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ScienceDirect
Procedia CIRP 33 (2015) 41 – 46
www.elsevier.com/locate/procedia

9th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '14

A reference ontology to support product lifecycle management

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Abstract

With the proliferation of systems generating huge amounts of product information and the increasing number of companies involved in the production processes, the efficient management of product lifecycle is becoming a challenging issue. The problem of maintaining a coherent structure to represent and link different pieces of information is crucial for companies aiming at improving their performances by reducing the time to search for particular information.
The need of developing models for such a complex information structure can be found in many works, which define semantic models and ontologies to represent and integrate information along the product lifecycle. However, some works address only specific cases, thus resulting in very detailed ontologies that model few portions of the product lifecycle and are not easily generalizable or usable, while other works define more general models, but did not provide concrete examples of applications in industrial domains.
The aim of our work is to propose a reference ontology to support PLM, general enough to represent the main concepts and relationships needed to manage the whole product lifecycle. Furthermore, the PLM reference ontology can be extended and specialized to manage specific product lifecycles by adding new entities, sub-entities and relationships to its structure. An example of a real application of the development and extension of the PLM reference ontology in an industrial case is reported. The work presented in this paper is supported by the EU-FP7 project amePLM.

Selection and peer-review under responsibility of the International Scientific Committee of "9th CIRP ICME Conference"

Keywords: Knowledge management; Product; Lifecycle; Ontology.

1. Introduction

Products generate a large amount of information during their lifecycles and small and medium enterprises (SMEs) are often not structured enough to enable its efficient management. Several tools of Product Lifecycle Management (PLM) have been developed in the last years to pool all this information.

The main goal of PLM is the management of all the processes and associated data generated by events and actions of various lifecycle agents (both human and software systems) and distributed along the product lifecycle phases, from the beginning to the end of life [1]. PLM systems are mostly used in the product design phases, but they can be used in each stage of the product lifecycle, to manage the information and data generated from different people and different tools.

Recent surveys evaluate that there are some difficulties for SMEs in the use of PLM systems [2]. SMEs do not exploit the full potentiality of PLM systems and a big amount of information and knowledge is being lost or requires a higher human effort to be preserved.

The main problem of SMEs in the exploitation of a PLM system is the lack of models to represent the product lifecycle. In fact, PLM is a software platform for integrating various tools needed by a production process, but it is not a methodology for information structuring and modeling. This article focuses on the development of a reference model to represent PLM, to help

Selection and peer-review under responsibility of the International Scientific Committee of "9th CIRP ICME Conference"
doi:10.1016/j.procir.2015.06.009

companies in understanding the philosophy of a PLM approach and help them in structuring their knowledge.

The rest of the paper is organized as follows. Section 2 describes the relevant literature available on the topic, while Section 3 describes the adopted approach to develop the PLM reference ontology. The following three sections describe the main phases of the ontology development process: (i) the identification of concepts, (ii) the definition of model, and (iii) the ontology implementation. Section 7 provides an example of the usage of the PLM reference ontology to represent a real product lifecycle. Finally, Section 8 draws conclusions and states future works.

2. Ontologies for PLM

Ontologies have already been proposed for knowledge management in a number of papers [3]. Since PLM is a complex organization of activities for product and process engineering management, starting from conceptual design, detailed design, engineering, production, and usage, including disposal and recycling, the main reasons for the development of ontology models for PLM are the need for a clear understanding of the product lifecycle phases [6] and the need of systems interoperability [7]. These reasons motivate the ontology-based data and knowledge representations to support the collaborations among the actors operating along the product lifecycle, resulting in expected lower efforts and shorter time to market.

In order to support the system integration, approaches dedicated to studying and developing semantic data models with concepts, relation and their respective properties, have been introduced [8][9]. For example, in [8] the authors addressed the development of a semantic assembly information model, which provides also additional reasoning capabilities to move towards semantic interoperability.

Ontologies have also been developed for closed-loop PLM [10] and for STEP [11]. A product design ontology that formalizes the functionality of shape processing methods in the design workflow is defined in [12], while an ontology to manage both the product and the PLM is proposed in [13] to automatically handling multiple data from multiple physical products and to support system interoperability and data integration.

The application of ontologies in product development is also fundamental to allow the knowledge sharing [14][15]. In [14] an information management system based on an ontological approach on design and engineering processes was developed, while [15] showed the benefits of applying ontologies to support knowledge sharing in PLM with a focus on manufacturing processes. By using a product ontology, [16] introduced an approach to support interoperability in Product Data Management (PDM).

In [17] an ontology for engineering design activities was described, even it was not implemented in software. An approach for conflict mitigation in collaborative engineering using ontologies implemented in a software module was presented in [18]. Another approach, also supported by software, was developed in [19] to allow the management of engineering drawings, in the context of ship-building. The work presented in [20] describes the SWOP project which focused on the application of ontologies and problem solving methods to develop optimized combinations for products and production systems in order to solve customer-specific problems.

Despite the diffusion of literature on ontological model for PLM, the concrete use of such system is not diffused in companies, especially SMEs.

3. Design of the PLM domain ontology

An approach to facilitate the development and usage of ontologies in application domains is to develop multiple ontologies with different levels of generality, from top-level ontologies to domain ontologies and application ontologies [21]. Top-level ontologies contain the definitions of general concepts that can be used in a broad area of applications. Domain ontologies represent the vocabulary for a generic domain independent of the specific applications, while application ontologies provide definitions of terms for a specific application in a particular domain [22].

This paper is focused on the development of the PLM domain ontology, some of which concepts were preliminary introduced in [23][24], and it also shows how the PLM domain ontology can be specialized in an application ontology.

To develop the PLM domain ontology we followed the four main phases of the ontology development process [15], as reported in Figure 1. In the first phase, the domain of interest is defined, usually by a text or oral description. In the second phase the domain is further analyzed and the set of concepts relevant for the domain are identified. Then, the concepts are organized in a model, e.g., using a UML formalism, to specify their properties and the relations among them. Finally starting from the model, the ontology can be implementing by means of an ontology editor, to have it in OWL.

As said, the domain on which we focused for the design of the ontology is the product lifecycle management, which is a complex domain, because it involve the management of different data, technologies, tools, processes and people. In the following sections we describe the three main phases to develop the reference PLM ontology.

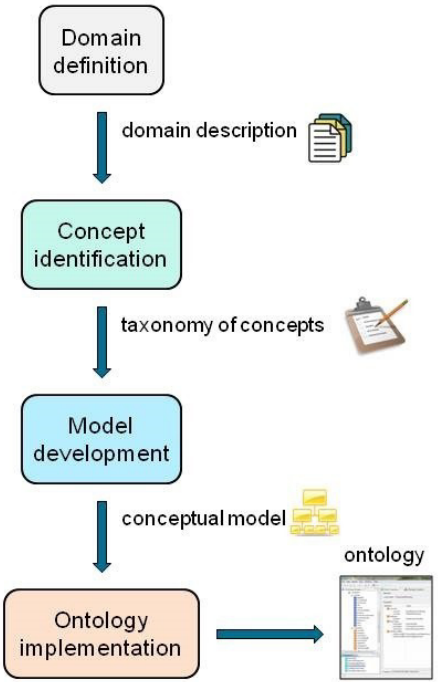

Fig. 1. Phases of the ontology design

4. Concept identification

The concepts used to describe a PLM system are reported in Table 1. This dictionary of PLM concepts is derived from various standards and books [1] which cover a broad array of industries and applications.

Table 1. Description of PLM concepts

Concept	Description
Product	A generic term for whatever is produced by a process and serves a need or satisfies a want.
Customer	The reference person of a company that ordered a product.
Project	The term used by a company to indicate the collaboration with a customer for the developing of a product. Each project refers to one product and is connected with one customer.
Product component	One of the hardware, electronic or software (e.g., parts, sub-assemblies) that make up a product. A component may be subdivided into other components, which combine into sub-assemblies and assemblies to define products. Each product can be made of several components, and the same component can be used by different products.
Material	The material of which a product or a product component is made of.
Physical characteristic	The physical characteristic (e.g., length, weight, etc..) of a product or product component.
Unit	The unit in which the Physical characteristic is measured.
Activity	An action executed during the product lifecycle of a specific product that can be univocally and un-ambiguously identified.
File	Electronic data managed and stored as a single object.
Document	A uniquely-identified block of information, that can be composed by several files.
Tool	A software tool used to produce a file, for which the name and the version have to be specified.
Resource	An entity that is involved in the execution of an activity. A resources can be of two kind, Person or Machine.
Role	The term used to define a specific sets of skills and responsibilities associated with the employees of the company.

5. Model development

An ontology can be expressed as a set of classes, relations among classes and properties of classes. Classes represent concepts and could be organized in taxonomies to define a hierarchical structure among classes. Relations represent associations between concepts and are usually binary. Attributes (also called properties) describe the features of the concepts. Finally, instances represent the real elements or individuals in an ontology.

We organized the PLM concepts in a formal model, shown in Figure 2 according to the UML class diagram formalism. The upper part of the diagram contains information about the product and its characteristics, while the most consistent part is focused on the product lifecycle management.

The class Product contains the information about products. The class Product is linked to the class Project because a product is developed during a project. the class Project is associated with the class Customer to store the involvements of customers in projects. A product is also associated to the Material class to store the material of the product, to the Product component class because each product can be made of several components, and to the Physical characteristic class because each product has its specific characteristics to be stored.

A Product is associated with the activities of its lifecycle. There are several kind of association between Activity and File, due to the different kind of usage of the file done by the activity. An activity can (i) consult a file, if it is simply read, (ii) have a file as input, if it is used and modified by the activity, and (iii) produce a new file as output. A file can be also connected to the product or product component it refers to. Furthermore, files or groups of files can be linked in a Document. For each file is known the software Tool exploited to produce it.

To keep trace of the people involved in the activities, the Person class, which is a specialization of the Resource class, was introduced, which include personal data and contacts. The other specialization of the Resource class is the Machine class, which represents the machines used in each activity. To each person is also assigned a Role, which specifies if a person can see an Activity, can use a Tool or can access to a File.

6. Ontology implementation

The ontology is a direct representation of the model described in the UML diagram. The classes in the UML diagram are concepts in the ontology with named relations between them having the cardinality restrictions and the names as defined in the diagram.

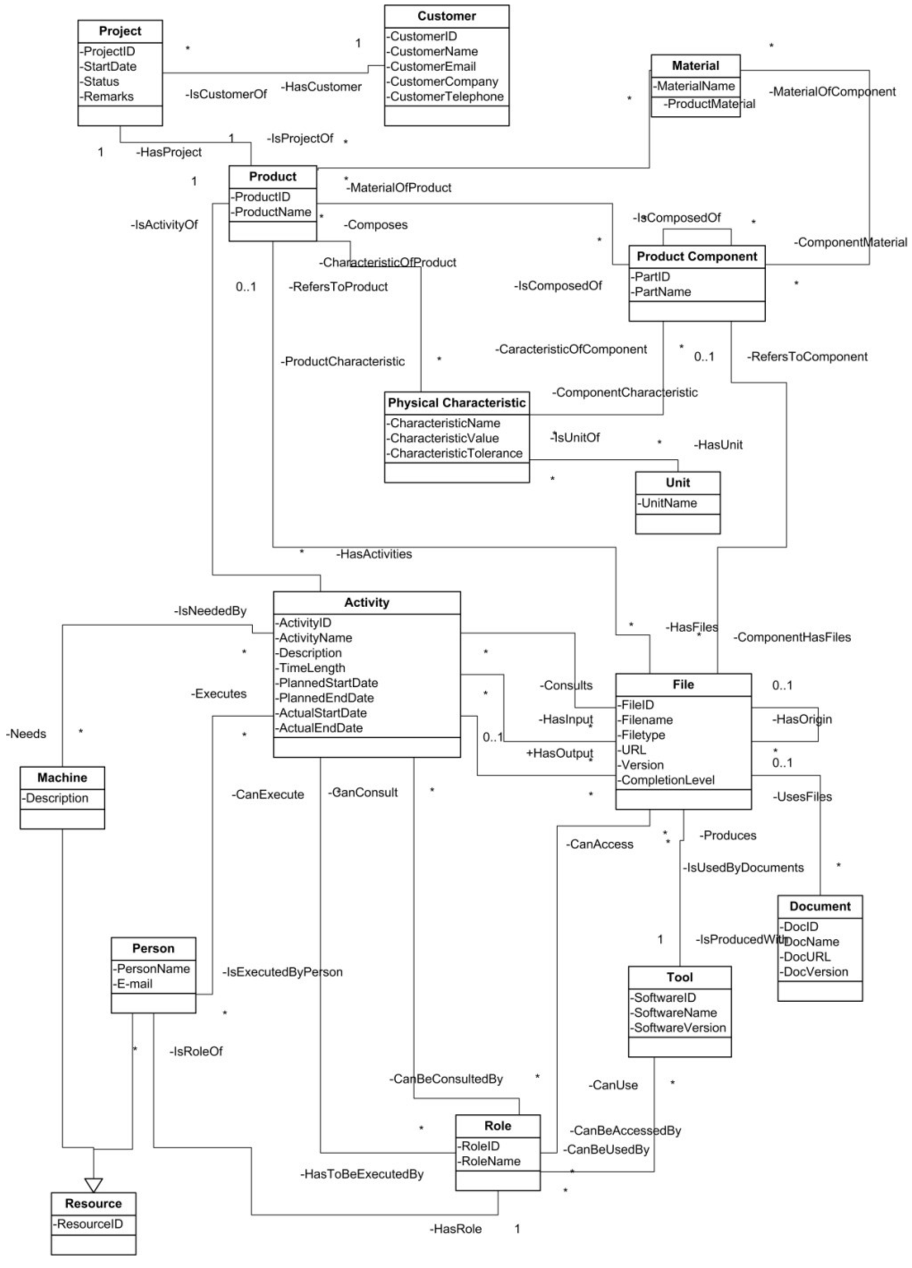

Fig. 2. UML class diagram of PLM

Our model can thus be used together with any repository offering URIs for the documents stored there. Figure 3 shows the screenshots of the developed ontology using the Protégé ontology editor [25].

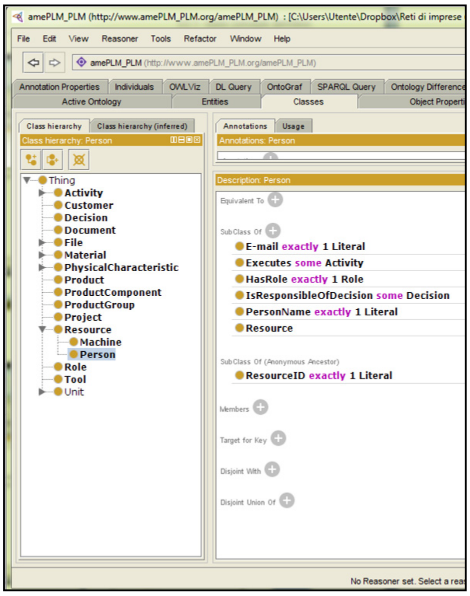

Fig. 3. Screenshot of the developed ontology in Protégé

7. Ontology specification and usage

In this section we provide an example of the usage of the PLM reference ontology in an application scenario. The application scenario regards a company focused on the production of telecommunication filters. The PLM ontology can be specialized and used to store data regarding the filter lifecycle and to easily retrieve the needed information. The specialization of reference concepts and the corresponding instances are summarized in Table 2, while the details about the filter lifecycle are reported in the following.

Table 2. Specialization of PLM concepts for the use case

Concept specialization	Instances
Product	
Filter	E15R01
Product component	
Sink termination	D10C99
DPX GSM	D13T02
Splitter LNA	D85A01
Activity	
Production	
Assembly filter	
Assembly sink termin.	Assembly D10C99
Assembly DPX GSM	Assembly D13T02
Assembly splitter LNA	Assembly D85A01
Final assembly	Assembly E15R01
Tuning filter	Tuning D85A01
Testing filter	Testing D85A01
File	
Bill of Material (BOM)	BOM_ E15R01.xls BOM_ D10C99.xls BOM_ D13T02.xls BOM_ D85A01.xls
Computer Aided Design (CAD)	CAD_ E15R01.xls CAD_ D10C99.xls CAD_ D13T02.xls CAD_ D85A01.xls
Assembly sequence	Assembly_E15R01.pdf Assembly_D10C99.pdf Assembly_D13T02.pdf Assembly_D85A01.pdf
LNA test	LNAtest_E15R01.pdf
Control plan	ControlPlan_E15R01.pdf ControlPlan_D13T02.pdf
Tuning plan	Tuning_E15R01.pdf
Role	
Manager	Plant manager Quality manager
Operator	Assembly operator

At the beginning of the lifecycle, the Project manager receives the order from a client to assembly a specific filter, identified by its code (e.g. E15R01). If he decides to accept the request, an instance of the Filter class is created, with code E15R01. The filter is composed by three components: a sink termination, a DPX GSM and a splitter LNA. The classes corresponding to these three components are created in the ontology, together with the corresponding instances. Furthermore, the links between the filter and its components are also inserted in the ontology.

The client sends to the company also the files needed to perform the assembly of the filter, i.e., the BOM, the CAD and the Assembly sequence for the filter and its components, together with the other files needed to tune and test the filter. The names and URLs of these files are stored as instances of the File class, and are connected to the corresponding filter or component.

The Project manager plans the assembly of the filter by creating an instance of the production activity, which is composed by several sub-activities: the assembly of the filter, further composed by the assembly of all components and the final assembly, the tuning of the filter and the testing of the filter. The ontology stores the instances corresponding to these activities, together with the files used by each activity and the responsible role for each activity.

In this way, during the filter lifecycle, the information about activities, files and resources are continuously stored in the ontology. This information can be used by all people involved in the product lifecycle. For example, when an assembly operator is notified of the presence of an assembly activity he has to perform, he has not to manually search for the CAD or BOM or Assembly sequence files, because they can be easily found by querying the ontology which stores all files related to the specific filter.

The presence of a customizable ontology is valuable because it allows the definition of specific search functionalities based on company needs. For example, instead of searching for information related to a specific filter, the company can be interested in searching the information about the filters similar to the one requested by a client. In this case, the similarity measure can be the percentage of equal components used to produce a filter and this score can be easily computed by using the data stored in the ontology. This information can also be used to decide the best operator to assign an activity, by computing the number of the same kind of activity performed on similar products.

8. Conclusion

In this paper we proposed a data structure to represent and link different pieces of information about PLM. This model, in the form of ontology, is at the basis of a more complex platform for the semantic management of product lifecycle. The main advantage of using our model is that it is simple and general enough to be adopted in different application domains and it allows the reuse of knowledge by reducing the time to search for particular information. We are currently applying our model in several application domains to show its flexibility and potentiality.

Acknowledgements

The research presented in this paper is supported by the EU-FP7 research project on Advanced Platform for Manufacturing Engineering and Product Lifecycle Management (amePLM). The authors would like to thank Alina Echert, from Romania Telecommunication Trading srl, for her kindness in providing the material for the application scenario.

References

[1] Stark J. Product lifecycle management: 21st century paradigm for product realization. Springer-Verlag, London 2005.
[2] El Kadiri S, Pernelle P, Delattre M, Bouras A. Current situation of PLM systems in SME/SMI: Survey's results and analysis. Proc 6th Int Conf Product Lifecycle Management 2009.
[3] Jurisica I, Mylopoulos J, Yu E. Ontologies for Knowledge Management: An Information Systems Perspective. In: Knowledge and Information Systems 2004; 6: 380–401.
[4] Brandt SC, Morbach J, Miatidis M, Theißen M, Jarke M, Marquardt W. An ontology-based approach to knowledge management in design processes. Computers and Chemical Engineering 2007; 32: 320–342.
[5] Kumar H., Park PS. Know-Ont: A Knowledge Ontology for an Enterprise in an Industrial Domain. International Journal of Database Theory and Application 2010; 3, 1: 23-32.
[6] McKenzie-Veal D, Hartman NW, Springer J. Implementing Ontology-based Information Sharing in Product Lifecycle Management. Academia.edu 2010.
[7] Abdul-Ghafour S. Integration of product models by ontology development. In: IEEE Int Conf on Information Reuse and Integration; 2012.
[8] Fiorentini X, Gambino I, Liang VC, Foufou S, Rachuri S, Bock C, Mani M. Towards an Ontology for Open Assembly model. In: Int Conf Product Lifecycle Management 2007: 445-456.
[9] Kwak JA, Yong HS. An Approach to Ontology-Based Semantic Integration for PLM Object. In: IEEE Int Works on Semantic Computing and Applications 2008: 19-26.
[10] Jun HB, Kiritsis D, Xirouchakis PA. Primitive ontology model for product lifecycle meta data in the closed-loop PLM. Enterprise Interoperability II: New Challenges and Approaches, Springer Verlag London 2007: 729–740.
[11] Wang Q, Peng W, Yu X. Ontology based geometry recognition for STEP. IEEE Inter-national Symposium on Industrial Electronics 2010: 1686-1691.
[12] Catalano CE, Camossi E, Ferrandes R, Cheutet V, Sevilmis N. A product design ontology for enhancing shape processing in design workflows. J Intell Manuf 2009; 20: 553-567.
[13] Matsokis A, Kiritsis D. An ontology-based approach for Product Lifecycle Management. In: Computers in Industry 2010; 61: 787–797.
[14] Lutters D, Mentink RJ, Van Houten F, Kals H. Workflow management based on information management. In: Annals of the CIRP 2001.
[15] Imran M, Young B. The application of common logic based formal ontologies to assembly knowledge sharing. In: J of Intelligent Manufacturing 2013.
[16] Panetto H, Dassisti M, Tursi A. ONTO-PDM: product-driven ONTOlogy for Product Data Man-agement interoperability within manufacturing process environment. In: J Advanced Engineering Informatics archive 2012; 26, 2: 334-348.
[17] Sim SK, Duffy AHB. Towards an ontology of generic engineering design activities. In: Res Eng Design 2003; 14: 200-223.
[18] Slimani K, Silva C, Ferreira D, Médini L, Ghodous P. Conflict mitigation in collaborative design. In: Int J Production Research 2006; 44, 9: 1681-1702.
[19] Lu T, Guan F, Gu N, Wang F. Semantic classification and query of engineering drawings in the shipbuilding industry. In: Int. J Production Research 2008; 46, 9: 2471-2483.
[20] Eckstein H. SWOP Project - Semantic Web-based Open engineering Platform, 2010: http://www.swop-project.eu/swop-approach/final-public-report.
[21] Guarino N. Formal Ontology in Information Systems. Proceedings of FOIS'98.
[22] Spath D, Lentes HP, Lentes J. Towards an ontology supporting the planning of production systems. Production Engineering. Research and development in Germany. Annals of the German Academic Society for Production Engineering 2005; 12, 2: 117-120.
[23] Antonelli D, Bruno G, Schwichtenberg A, Villa A. Full exploitation of product lifecycle management by integrating static and dynamic viewpoints. IFIP Advances in Information and Communication Technology 2013; 398: 176-183.
[24] Bruno G, Villa A. The exploitation of an ontology-based model of PLM from a SME point of view. 7th IFAC Conf on Manufacturing Modelling, Management, and Control 2013: 1447-1452.
[25] http://protege.stanford.edu/